UNIVERSITÄT BREMEN

CPT device

Redesign to making it useful

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Arose needs of use with the previous CPT and that create the need to remake another CPT device, and that project was for it.

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1. REPORT

1.1. Aim

CPT is a device that has 70 year-old of existence. It could seem that is too much for now redesigning one, and each year too. But using these devices new inconvenient or needs appear. That is why that project has existed.

That project has as target redesign CPT device to test the Sea bottom because previous ones did not work as it was requested or new needs arose.

The new CPT should be more simple as previous, instead of two areas for four DMS, just one. Previous ones had an item that subjected the “Test-stick” and it slid, that mechanism had problems when pressure becomes higher, because of it slides the house bent and water came in and damage CPT.

The arose needs were easy accessibility to inner, when the items turns by joining of threads the wires should not turn too, the Test-stick should receives all the impact of CPT against to Sea bottom, that way we will have a right measure of soil’s hardness.

1.2. Background

1.2.1. Definition of CPT

Cone Penetration Testing (CPT) is a versatile, time efficient method to geotechnical characterise sediment strength and pore pressure in offshore settings and on land. The majority of the penetrometers rely on heavy trucks (figure 1.2.1.A) or rigs to provide the necessary force to push the CPT probe into the ground. But in this project is developed a CPT for work with the Sea bottom. In that chase the CPT is dropped by a ship form the surface of Sea, then it is going down by its weight (figure 1.2.1.B). It is linked to the ship by wire. When CPT impacts again to bottom its Test-stick is bent. After that CPT is recuperated pulling the wire.

Figure 1.2.1.A **Figure 1.2.1.B**

1.2.2. History: Origins

Cone penetrometers were first of all used for *in situ* determination of the stiffness of the penetrated material (soil or sediment; here: Sea bottom). In the Roman era, the number of slaves, which were required to push a certain rod into the ground, was used as a measure for the strength of the ground. This crude method to quantify the strength can be considered as a forerunner of cone penetrometer devices, standing out today for an effective ground probing instrument. The first cone penetrometer tests, as we know them today, were carried out with a mechanical cone penetrometer by the Dutch engineer Barentsen. The principle of this so-called Dutch cone based on a gas pipe with an inner diameter of 19 mm and a steel rod, which could move vertically (up and down) freely inside the pipe (Figure 1.2.2.A) . A 10 cm² cone with a 60° apex angle was attached to the steel rod and both, the pipe and the rod, were manually pushed stepwise into the ground, therefore reaching a remarkable penetration depth of up to 12 metres. The penetration resistance was measured by a manometer. This instrument represents the first version that evaluates pile bearing capacity.

A decade later, the Dutch device was parlayed with an “adhesion jacket” behind the cone by Begemann, which additionally measured the local skin friction. Begemann was the first to postulate, that the friction ratio (ratio between the sleeve friction and the cone resistance) can be used for a classification of the profiled soil layers in terms of soil type (e.g. clay, silt, sand). Although further principles of mode of operation, mainly hydraulic penetrometers, have been developed, mechanical cone penetrometers are still widely used (Figure 1.2.2.B). The first electrical cone penetrometer, where the signals were transmitted to the penetrating probe in the ground via a cable inside the hollow penetrometer rods, was developed in Berlin at the Deutsche Forschungsgesellschaft für Bodenmechanik (Degebo) during the 2nd World War. Providing continuous testing with a constant penetration rate, elimination of uncertainty given by friction of the inner rod and the outer rods of the mechanical penetrometer and the higher accuracy of the much more sensitive load cells describe the main improvement of electrical cones in contrast to mechanical ones. In 1965, the company Fugro developed an electrical cone, whose geometry formed the basis for the International Reference Test Procedure (ISSMEFE 1989; Lunne et al. 1997). Among other things, it was established, that “standard” CPT deployments were to be carried out at a constant rate of 2 cm/s. In addition to the determination of penetration resistance, pore pressure measurements were performed with piezocones, which were deployed adjacent to CPT profiles. In 1974, the first piezocone developed by the Norwegian Geotechnical Institute was presented. The first published combined measurements of cone resistance and pore pressure were carried out in sensitive Canadian clays by Roy at 1980. In the progressing development of cone penetrometers they were fitted with different sensors, measuring physical and geotechnical parameters such as density, salinity, and conductivity. A detailed overview is given given in Burns and Mayne (1998).

An appropriate improvement took place in the 1970ies, when on-shore devices have been modified for seagoing use (e.g. Dayal 1978; Schultheiss 1990). Depending on the penetration depth, two different principles of instruments were developed. To reach deep penetration (tens of meters), rigs are required, which have to be lowered to the seafloor and then push the cone by hydraulic force with constant velocity into the sediment. To the contrary, lance-shaped free-fall cone penetrometers were lowered on a cable or freely dropped, running through the water column and penetrating the sediment with their own momentum gained through their acceleration and weight. The non-constant penetration velocity and depth is determined by the cone’s momentum and the stiffness and cohesion of the sediments. Penetrating only surficial sediment down to 10 meters maximum, the free-fall devices do not disturb the uppermost soft layers as heavily as the rigs. Hence, artefacts in CPT results from consolidation by the rig are avoided.

The actual standard geometry of a cone available for on- as well as off-shore CPT application consists of a 60° cone with a 10 cm² base area and a 150 cm² friction sleeve located above the cone. In addition, 15 cm² cone penetrometers (diameter = 43.7 mm, sleeve area = 225 cm²) are used, especially in case of incorporation of additional sensors (e.g. pore pressure sensor) into the probe . For offshore seabed tests, 15 cm^2 cones are preferred. The influence of the different geometry of the 10 cm² (standard) and the 15 cm² cone can be neglected, as in practice cone penetrometers range in cross section from 5 cm² to 15 cm² give very similar corrected cone resistance data.

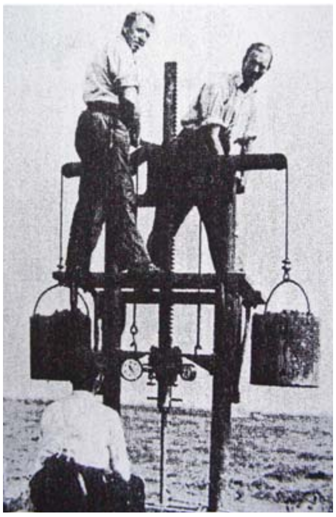


Figure 1.2.2.B **Figure 1.2.2.A**

1.2.3. Cone Penetration Parameters

Generally, tip and sleeve readings and pore pressure measurements during insertion of a cone penetrometer into the sediment produce a profile measuring geotechnical properties. The tip as well as the sleeve of a penetrometer are equipped with strain gauges to measure stresses exerted by the sediment during penetration. Cone resistance q_c is defined as the force acting on the cone tip devided by the area of the cone, and sleeve friction f_s results in the force acting on the friction sleeve devided by the area of the sleeve. Pressure transducers detect the ambient pore pressure u during measurement on a port on the cone tip (u_1 position), on the cone shoulder (u_2 position) and/or behind the friction sleeve (u_3 position).

The measured cone parameters underly a certain variability, which is generally caused by the heterogenity and diversity of the sediment and a certain degree of error in testing procedures. Inherent sediment variability is given by natural, often superimposed geological processes, whereas measurement error is based on inaccuracies of the measurement system and variations in equipment geometries. During penetration, the cone causes a material to deform elastically, plastically or fail within a spatial volume in the vicinity of the penetrometer during insertion of the instrument. This means the measurements are not absolute point measurements, but represent the extent and the characteristics of the failure zone, which again depend on physical properties of the material (e.g. stiffness, plasticity, consolidation, density, water content). In general, firm materials are compressed upon penetration of the instrument, while pore fluids either cause high excess values (low permeability sediments) or get displaced (high permeability in loose sands), the latter resulting occasionally in subhydrostatic values. In soft, fine-grained sediments, clay fraction particles migrate radially from the axis of the penetration path and may get suspended by the fluids when stress is induced by insertion of the cone. The effects described here are more pronounced in dynamic (free-fall) CPT deployments than in constant rate tests (2 cm/s).

Cone resistance

One of the major challenges in cone penetration testing is the establishment of a systematic relationship between q_c (and f_s for that matter) and sediment physical properties such as bearing capacity or undrained shear strength. In general, penetrometrists either correlate cone resistance q_c with a given set of sedimentary physical properties, which can be used to calculate cone resistance for geotechnical and geological application (e.g. liquefaction, slope stability), and/or carry out back-calculation of sediment physical properties from measured cone resistance (e.g. undrained shear strength). To reduce the variations of the input strength, which can produce large deviations in the calculation of cone resistance, theoretical solutions are used. A large number of theoretical analyses have been carried out, but none of them is rigorous. All those models are generally confronted with large deformations and a non-linear behaviour of the sediment. The failure zone due to penetration of a cone can commonly divided into a plastically deforming region and, at some distance, an elastically deforming region, whereas along the lance-sediment interface intense shearing remoulds the material. The extent of this failure zone depends mainly on shear strength and the shear modulus of the sediment. A variety of theoretical solutions for cone penetration have been proposed in the past approaching the penetration problem with different theories. These include: i) the bearing capacity theory (Terzaghi 1946), ii) the cavity expansion theory (Bishop 1945), and iii) the strain path method (Baligh 1985).

For the bearing capacity theory (i), the cone resistance is assumed to be equal to the collapse load of a deep foundation in the soil. The extension of this theory to penetrometer analysis assumes a failure mechanism. Chari and Abdel-Gawad (1981) summarise theoretical failure analysis by Meyerhof (1961), Terzaghi (1946) and Durgunoglu and Mitchell (1973) (Figure 1.2.3.A).

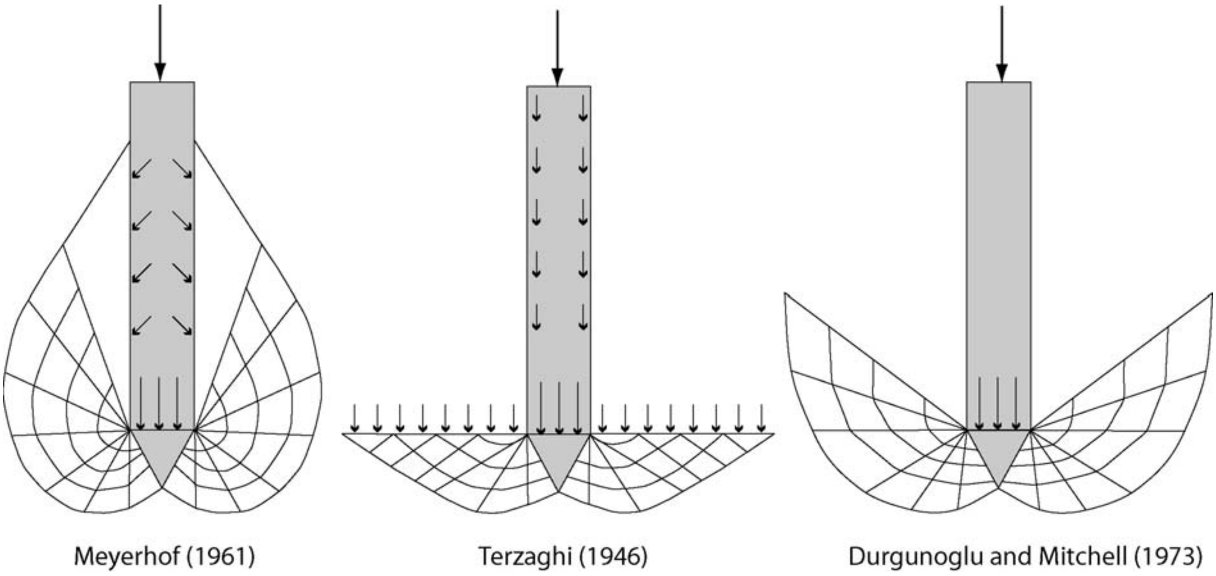


Figure 1.2.3.A

The limitations of this theory are in the neglect of the material stiffness and the compressibility as well as the ignorance of the influence of the penetration process on the initial stress regime around the cone shaft. Consequently, this theory is usually adapted to shallow penetration, which involves a mechanism where the displaced material can escape as an entity to the surface. In deep penetration, however, the displacement is controlled by elastic deformation of the material. Satisfying the latter, the cavity expansion method (ii) is used regarding the force required to produce a (deep) hole in an elastic-plastic medium, which is equal to expanding a cavity of the same volume under the same conditions (e.g. Salgado et al. 1997; Yu and Mitchell 1998). Thus, elastic and plastic sediment deformation during cone penetration are taken into account as well as the influence of the penetration process on the initial stress regime and the effect of stress around the tip, in turn influencing q_c. Prior to this, Yu and Mitchell (1998) demonstrated that preponderant cavity expansion solutions give the closest agreement between predicted and measured resistance values. The strain path method (iii) is an improvement of the cavity expansion theory, as the latter does not model the strain paths correctly (Baligh 1986a). Baligh (1986a) suggested the application of the strain path method to account for the complex deformation history of the sediment during cone penetration.

These theoretical approaches were used to interpret the strength of fine-grained, cohesive sediments based on CPT/CPTU data. The *in situ* undrained shear strength depends on sediment failure, anisotropy, stress history and strain rate. Regarding the non-linear stress-strain behaviour due to cone penetration, no single value for undrained shear strength exists. Nevertheless, theoretical analysis describes the relationship between cone resistance and s_u as follows:

$$q_c = N_c \times s_u + \sigma_o \quad ,$$

with the theoretical cone factor N_c , and the total pressure σ_o (see Lunne et al 1997). Depending on the theory used, σ_o may be $\sigma_{uo,}$ $\sigma_{ho,}$ or σ_{mean} (Lunne et al. 1997). A lot of solutions for the cone factor are given in a summary by Lunne et al. (1997; see their Table 5.5). As theoretical solutions simplify the complex phenomenon of cone penetration, they have to be verified from actual field and laboratory-based data, which estimate s_u from CPT data using the following equation:

$$s_u = \frac{q_c - \sigma_{vo}}{N_k} \quad ,$$

with the emperical cone factor N_k and the total stress $\sigma_{uo.}$ Depending on the sediment, N_k ranges between 11 and 19 for normally consolidated marine clay (Kleven 1986), and averages 17 for non-fissured, overconsolidated clays (Kjekstad 1978). The relationship between s_u and q_c is modified with CPTU employing the cone resistance corrected for pore pressure effects:

$$s_u = \frac{q_t - \sigma_{vo}}{N_{kt}} \quad .$$

The corrected cone resistance is represented by $q_t = q_c + (1-a) \times u_2$, with u_2 = the measured pore pressure and a = area ratio of the cone, which is defined as the ratio between the cross-sectional area of the strain gauge and the cross-sectional area of the cone. In CPT nomenclature (q_t - σ_{uo}) is named as the net cone resistance q_{net}. Depending on the plasticity N_{kt} ranges between 10 or less and 20 for normally consolidated clays (see Table 3 in Karakouzian et al. 2003). Often used values are N_{kt} = 10, 12, 15 (e.g. Baltzer et. al. 1994; Sultan et al. 2007a).

Numerous geotechnical sediment parameters of (e.g. deformability [expressed by constrained modulus, elastic modulus, shear modulus], stress history) may be derived from cone resistance, but they are not further considered in this thesis.

Sleeve Friction

The frictional force exerted by the sediment onto the friction sleeve of a CPT cone during penetration defined as sleeve friction f_s. Similar to cone resistance, it is measured using electrical strain gauges mounted onto the stainless steel core of the CPT probe. The friction sleeve is similar to cone geometry subject to CPT standards and has a defined area depending on the diameter of the cone (for 10 cm^2 cone = 150 cm^2 and for 15 cm^2 cone = 225 cm^2). Different arrangements of the CPT strain gauges are used:

(i) cone resistance and sleeve friction are detected by individual, independent strain gauges during compression while the instrument penetrates,

(ii) the sleeve strain gauge measures in tension while cone is recorded by a compressional strain gauge, and

(iii) the cone strain gauge and the sleeve strain gauge are connected to the same stainless steel core to record q_c and f_s. The sleeve friction is finally obtained by the difference in load of the friction sleeve and the cone resistance strain gauge.

Configuration (iii) is referred to as the "subtraction cone", which has been demonstrated to be more robust. Sleeve friction f_s is used for soil classification, one of the most important issues in CPT profiling. The friction ratio, F, calculated by dividing sleeve friction by the net cone resistance (q_{net}), is believed to provide a first-order description of the soil type as a repeatable index for the mechanical behaviour of its *in situ* properties adjacent to the CPT probe. A tentative application of that first-order soil classification was undertaken with data obtained with the SW-FF-CPT in fine-grained harbour deposits and brackish sediments. Recent studies have shown that the measurement of sleeve friction f_s is less accurate and less reliable than that of cone resistance in spite of corrections for pore pressure effect. Consequently, f_s is of subordinate importance in comparison to cone resistance q_c and pore pressure u, which both are viewed as the key parameters in CPT studies. In this thesis, sleeve friction was measured in each profile, but its interpretation was omitted for the above reasons on most occasions.

Pore Pressure

Pore pressure is simply the pressure of the fluids in the voids between the solid grains of the sediment matrix. It should be noted that only saturated matrices will be here considered as they are most relevant for marine sediments. In any marine geological environment realm the surrounding pressure is measured and defined as the pore pressure consisting of a hydrostatic component u_o resulting from the thickness of the water column, and an excess pore pressure component Δu in the sediment due to loading:

$$u = u_o + \Delta u \quad .$$

Excess pore pressure u can be consequently estimated to be zero, if hydrostatic conditions occur in the sediment (Figure 1.2.3.B). Nonhydrostatic pore pressure provides direct evidence for advection of pore fluids in the sediment, glacial, tectonic, sedimentary or antropogenic loading, or dynamic processes such as earthquake tremor.

An insertion of any kind of probe into a sediment causes changes in the stress and pore pressure regimes surrounding the penetrometer. The total magnitude of measured pore pressure during penetration tests consists of the hydrostatic component u_0, the excess pore pressure due to changes of the normal stress $\Delta\sigma_n$ resulting from the displacement of material by the insertion of the probe, and on excess pore pressure due to changes in the shear stress, caused by the shear deformation of the soil adjacent to the cone body:

$$U = u_o + \Delta\sigma_n + \Delta\sigma_{shear} \quad ,$$

(Figure 1.2.3.C). Both $\Delta\sigma_n$ and $\Delta\sigma_{shear}$ comprise a stress component induced by the profiling CPT lance and another component of pre-existing (excess) pore pressure in the geosystem. The zone of the influence of the normal stress is considered as a function of the stiffness, as expressed by the rigidity index I_r. In field measurements, pore pressure is defined as a total magnitude response of $\Delta\sigma_n$ and $\Delta\sigma_{shear}$ and can be only distinguished in an analytical way.

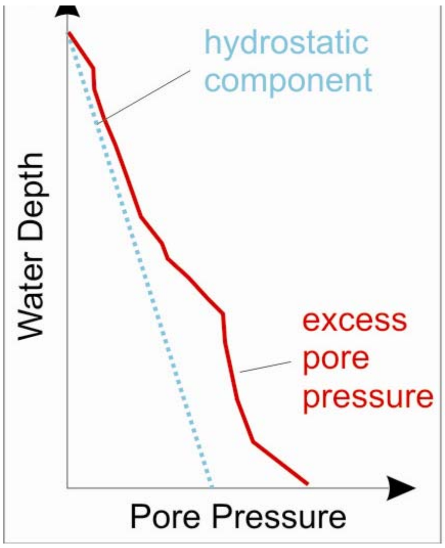


Figure 1.2.3.B (hydrostatic and excess pore pressure in marine sediments)

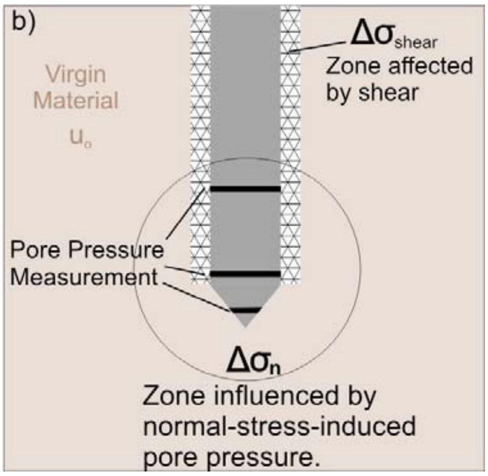


Figure 1.2.3.C (mechanical components of pore pressure during insertion of the probe (modified by Burns and Mayne 2002))

Considering a measured pore pressure signal, it can be divided into two different parts that contain different geotechnical as well as geological informations. The first part of the signal is characterised by a pressure pulse associated with probe insertion and the sediment properties followed by an evolution of the insertion pore pressure over the time, which formed by the insertion response depends on *in situ* permeability. When the instrument is halted over a long period of time, the induced pore pressure will approach its ambient conditions, which is the final component of pore pressure evolution. The duration, which is needed for the complete decay of the insertion pore pressure as a function of the permeability of the sediment varies between days and months. The dissipation decay may record two different signals. Burns and Mayne assume that the dissipation of the shear-induced pressure occures more rapidly than that of the cone-induced pore pressure, as the volume of sediment affected by the frontal impact is much larger than that affected by the sliding probe. Dissipation tests performed in soft, fine-grained silts and clays show a monotonous decrease of pore pressure (similar to observations in the laboratory one-dimensional consolidation tests). In contrast, dissipation tests in heavily overconsolidated fine-grained sediments often reflect dilatory pore pressure response with an increase in pore water pressure followed by a decrease and a return to hydrostatic values. Similar to the cone resistance, many analytical approaches have been developed to describe the changes in pore pressure during and after an insertion of a probe into sediment. This also includes the same theoretical solutions as mentioned in the context of cone resistance. An overview of the historical development of piezocone dissipation modelling until the 1990ies is given in Burns and Mayne. The theoretical analysis of dissipation of pore pressure based on the consolidation theory was used to predict the coefficient of horizontal consolidation C_h, from time taken for 50% of the maximum insertion pore pressure U_{imax} to dissipate (t_{50}) (Bennett et al. 1985):

$$C_h = \frac{r^2 \times T_{50}}{t_{50}} \quad ,$$

where r is the radius of the probe and T_{50} is a dimensionless time factor. Calculating C_h, the permeability k can be determined as follows:

$$k = \frac{C_h \times y_w}{D} \quad ,$$

with D = constrained modulus and y_w = unit weight of water.

As the failure zone during penetration is a function of the stiffness expressed by the rigidity index $I_r = G/s_u$, Bennett et al. 1985 suggest an emperical relationship for soft marine sediments between U_{imax} and undrained shear strength as

$$s_u = \frac{U_{i\max}}{6} \quad .$$

Based on the theoretical solution, when the soil is modelled as an elastic, perfectly plastic material, it follows:

$$U_{i\max} = s_u \times \ln\left(\frac{G}{s_u}\right) \quad ,$$

with G being the elastic shear modulus (Randolph et al. 1979).

An essential aspect of pore pressure measurement with cone penetrometers is the position of the pressure port. Due to changes in normal stress during penetration, the largest effect on the magnitude of pore pressure is under beneath the cone, whereas the relative changes in shear stresss are small (<20%; see Baligh 1986b). It has been long known that the pore pressure measured at the cone (u_1) is higher than measured behind the cone (u_2) or along the. Song and Voyiadjis (2005) described in detail the pore pressure behaviour taken at the different locations during penetration tests in a calibration chamber (33% kaolin - 67% fine-grained sand) with a constant penetration rate of 2 cm/s. The pore pressure responses for the u_1 and u_2 position show a similar trend with an initial increase followed by the decay to steady-state (constant equilibrium conditions such as stabiliszed pore water flow and stress-strain conditions). In contrast, the u_3 pressure signal is characterised by an initial fluctuation with an increase followed by a derease before it increases again to reach the steady-state. The absolute values of the steady state condition at the end of the penetration process are higher the closer the pore pressure is measured near the tip. The decrease of the signal is assumed to be linked with a dilative behaviour of the specimen caused by ligthly overconsolidated conditions (OCR = 1.5). In addition to the pore pressure signal and its absolute magnitude, the position of the pore pressure port influences also the dissipation behaviour. In lightly over-consolidated as well as normally consolidated specimens, the induced pore pressure measured at u_1 dissipates more rapidly than that in u_2 position.

1.2.4. Geological Application of Cone Penetration Testing

Cone Penetration Testing provides measurements to determine the strength (q_c), cohesion (f_s) and the pore pressure (u) of profiled sediments. Considering the geotechnical aspect of them, both they seem to be controlling factors for (saturated) sediment behaviour and stability. Saturated sediments can be considered as a two-phase-system, where the voids between the solid particles are filled with fluid (Figure 1.2.4.A). Depending on the cohesion forces acting between the grains, the skeleton of the solids is characterised by a certain strength, which is largely a function of mineralogical composition. On the other hand, the forces of the pore water (i.e. pore pressure) are counteracting the binding forces between the particles, and hence lower the strength. This relationship is expressed in the principle of effective stress (σ') presented by Terzaghi (1946):

$$\sigma' = \sigma - u \ ,$$

where σ = total stress and u = pore pressure. Relating to the stability of (saturated) sediments and modifying the Mohr-Coulomb relationship with respect to effective stress, it can be expressed as follows (Terzaghi 1946; Hubbert and Rubey 1959):

$$\tau = c' + \sigma'_n \times \tan \Phi \quad .$$

The equation implies that overpressuring weakens the sediment as the fluid is sustaining an extra part of the stresses acting against the granular skeleton. As a consequence, both the overall, and the interparticle friction ($\sigma'_n \tan\Phi$) are reduced. This means that it is the effective stress rather than the total stress, which controls deformation and stability of sediments. The occurrence of overpressuring is often combined with fine-grained, cohesive sediments characterised by low permeability and linked with geological processes such as tectonic deformation, mineral dehydration, decomposition of gas hydrates, hydrocarbon formation and high sedimentation rate. In these scenarios, the expulsion of the pore fluid is not in equilibrium with the reduction of the pore space by consolidation (Figure 1.2.4.B) (e.g. Schultheiss 1990; Maltman 1994). Generally, the reduction in effective stress (and strength) by overpressure is a crucial factor in all scenarios of sediment deformation and mass wasting (Hampton et al. 1996; Mienert 2004). This fact underlines the necessity of pore pressure measurement, which is only *in situ* possible. Going back to cone penetration testing, these devices establish synchronous and continuous *in situ* measurements of both (strength and pore pressure), which are vital to study different kind of potential failure mechanisms of sediments.

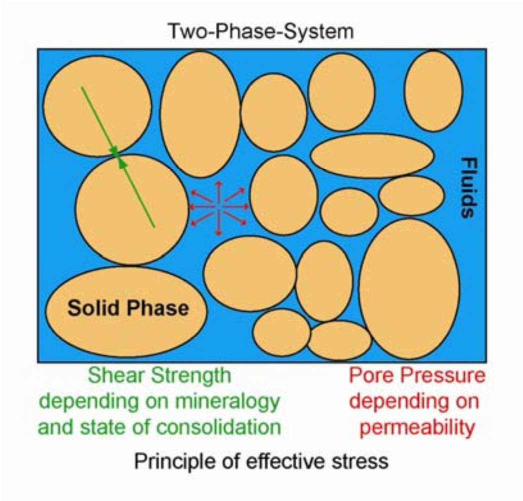


Figure 1.2.4.A (micro-scale view on forces acting in water-saturated sediments)

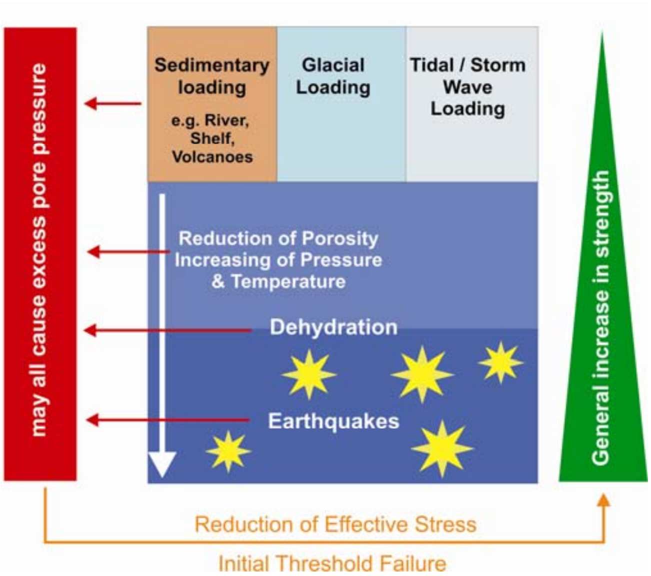


Figure 1.2.4.B (geological processes influencing effective stress)

Cone penetration is also a very suitable method for landslide studies as it is possible to identify failed and non-failed sediment bodies by their *in situ* physical properties. Remoulded sediment for example is characterised by a lower cone resistance and sleeve friction. In intact sediments adjacent to failed sediments, the shear surface can be detected by a decrease of the measured strength, because failure almost always occurs in the weakest material. Determining different pore pressure regimes is also critical to figure out the role of pore pressure in failure and may further serve to reconstruct historical events. A further application may be the study of the dynamics of surficial sediments in terms of liquefaction. Such a kind of fluidisation is associated with a build up in the pore pressure due to loading rather than pore water advection. If the pore pressure exceeds the confining (i.e. effective) stress, the particle skeleton is supported by the fluid and the sediment. Another aspect is long-term pore pressure measurement. As the pore pressure regime is influenced by various processes), which are characterised by different geo-dynamic processes, pore pressure observations on different time-scales are a crucial contribute to geo-mechanical studies. Therefore the piezocone has to be arrested for a defined duration in the sediment to collected ambient data.

1.3. Design requirements

That project exists because of there are needs that required being solved for obtain what we want to make better in the new CPT.

For a better focus, these need are classified in three ambits.

1.3.1. Needs for work

- When the cone impacts into the ground the test stick gets a deformation possible to admeasure with the four DMS settled in strategic positions on test stick.
- Have a house to protect the electric parts, test stick and DMS of water.
- Competence for being unalterable at high pressure and get a good work.
- Room for electronic parts.
- A tube for sending water to the ship.

1.3.2. Needs for assembly

- Access to the parts easily.
- It does not twist the wires when it is being assembling the parts.

1.3.3. Needs for make

- Standard cone:
    - As CTP's cone is catalogued around the world and in MARU that are another kind of CPT device using these standard cone, in that project it is thought that keeping standard cone will be comfortable in finding a cone when will be required.

- Standard threads:

- Created a new thread it is only when the market does not solve you needs and you can not redesign your devise for adapting it to the normalization. But in that project it is possible square the threads we need to the normalization.

- Standard rubber gaskets.
    - Same as in standard threads.

1.4. Solution

1.4.1. Sealing

For keeping dry the inner of CPT it's provided by rubber gaskets in every assembly of two items. Those links are made by thread, but before the thread there is one O-ring in a groove like it is showed in picture 1.4.1.A. O-ring is working when is deforming itself by the pressure and sliding between the items, and it is placed in a part in the middle of items' faces, look at picture 1.4.1.A.

For choosing the O-ring, first it was thought about the work's conditions that were wanted to work. Those were maximum 100 bars of pressure, that means 1000 meters of depth, temperature of 4°C, average temperature of the sea, and work with seawater. At catalogue 1.4.1.B is chosen the material of O-ring, that one is NBR, inasmuch as it has the first mark for work in those conditions.

The thickness of O-ring depends on the internal diameter, that's important to know for designing the groove that is going to fit the rubber gasket and works in optimum conditions.

In that project. About the size of the rubber gasket required for that project are:

- Test-stick has two of them and the internal diameter required is 10 millimetres. Then in stalemate the thickness for it is 1 millimetre, and the size of groove for keep in the rubber is 0, 85 depth and 1, 15 width.

- Cone and joint need a rubber of 34 millimetres of internal diameter. And Closet needs one of 36 millimetres internal diameter. Those two internal diameters have 2 millimetre of thickness and the size of groove is 1,7 depth and 2,3 width.

Then it is needed to be conscious to design the space of 0,08 millimetres, as said in stalemate, between the two items assembled because in that space is going to be the rubber when it is sealing.

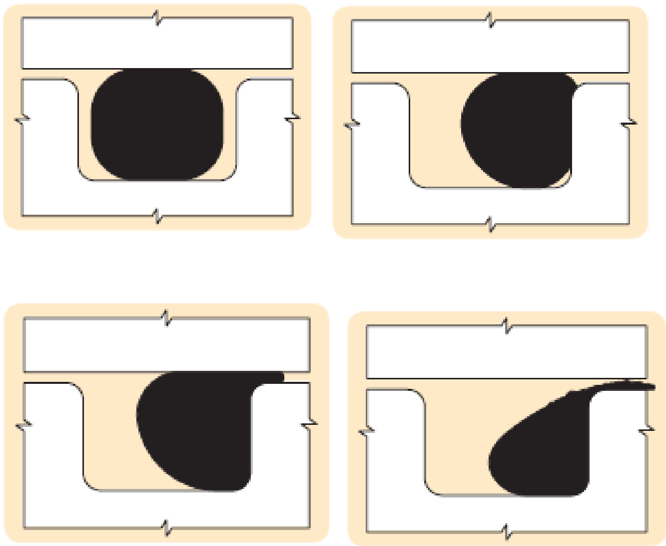


FIGURE: 1.4.1.A (pictures from „ Parker O-ring Handbook“)

1.4.2. Enabling access

Every joint is done by sealed threads and jut one with tampon that is also easy to remove, that one is the joint for fixing the wires through the “Closet” and at the same time for sealing.

Threads give a strong connection between items and easy way to disassemble.

1.4.3. Wires entangled

At time to assembly the items by threading them, the cables go through the CPT had the matter when the items, that they are fixed, turned the wire also and then a little chaos was created bad for working.

The Solution was devise an item, that users can manipulate easily and where part electric (chip) can be fixed and at the same time, join the other parts to it without fixed the cables (of chip) until the parts are joined.

That item is “Joint”. User gets and fixes the chip to the side determinate, then he makes to pass the cables through the hole that Joint has for them, at that time he gets the Test-stick to turn it to the concentric hole in the Joint, now Joint and Test-stick are connected without any cable clutter, the only thing that remains to be done is set the wires with DMS to the surface of Test-stick.

1.4.4. Keeping different pressures

In that CPT we need to keep 1bar inside of the CPT under water with 200 bars of pressure. What it is devised was that when water goes up through the CPT, conduct it by steel tub, at first step water goes in the Cone, the goes up through the Test-stick, crosses the Joint and then by a steel tub that its only function is to keep the pressure of 200 bars in and 1 bar out of itself, water goes out of CPT.

There is a chamber connected to CPT as it is showed in 1.4.4.A. In that chamber we should keep a pressure of 1 bar or 200 bars depending on what is required for the experiment. When it is 200 bars, the same pressure as water, the tub that drives water through that chamber it does not matter if it is made from rubber or steel, but when we should keep 1 bar, different as water and the same pressure as CPT the tub should be made of steel, so it is connected an steel tube to the steel tube protruded from CPT.

Another point to attack is the threads and all of them are sealed by O-rings, that part is explained in 1.4.1.Sealings.

1.4.5. Enabling to measure the micro-deformations

When Test-stick get a deformation from the impact to the soil we have four DMSs settled on its surface. DMSs are settled in specific ways, in couples of two that are on the opposites sides and in the opposite directions, those directions are different in both couples, one is up-down and the other one is left-right.

Market has a vast of DMSs. They are classified by rates; it depends on how are micro-deformations. To determinate which DMS we need in our CPT, in workshop, Test-stick was overloading with simulation of the force will have on the seabed. That part of calculus is on 3.1 Test-stick.

1.5. Final result

1.5.1. Explanation of CPT developed

Have a look at 4.1.2 CPT sectioned.

That CPT will be used “in situ”, from a ship it will be dropped to the Sea, then it will go down until push the Sea bottom. Say that all steel items are joined by threads.

The “Cone” is the tip of CPT, and works as arrow tip in an arrow, moving the fluid it is crossing, water and soil when it is at the Sea bottom.

The Cone has a hole where water comes in to the inner of Cone, but before water crosses that hole there is a porous O-ring, that has as function filtrate the impurities of Sea water, in that way we are saving beforehand that some impurities obstructed the tub’s inner and then having problems to take right measures or to make capsules and to broke by pressure.

Subsequently that water will through all the CPT, going up by Test-stick and pipe to the ship. That water will be used to know the pressure in different depths and other properties.

When water is inside of Cone, goes up crossing the Test-stick joined to Cone by thread, in order that water does not coming out of established rout for it there is an O-ring at the begin of thread, there is also another one, same size at the opposite extreme of Test-stick joined with the Joint.

Water goes through the Joint for short way, then comes in the Tub going up until it is outside the CPT. Tub is connected with a tube that gives to water a way to go to the ship.

That process of water going up through the CPT is during the while of CPT is descending to the bottom. Below it is explained when CPT arrives at the bottom.

Cone impacts to soil and cone goes into it. That impact produces a deformation in the Test-stick because of the Cone is only connected to the Test-stick, although it seems that House too. Between the Cone and House there is a porous O-ring that though is used for filtering the water is also used for not receiving the impact, so it is soft and it is crushed by the impact to the ground. That way Test-stick receives all the impact and is deformed.

There are 4 DMS settled on the surface of Test-stick in different ways to measure micro deformations that Test-stick could have. The information that DMSs get, goes by wires from DMSs to a microprocessor through the Joint. That microprocessor is settled at the inner bottom of the Closet, then another wire goes up to the ship.

1.5.2. Personal Conclusions

When I started the project with Dr.Achim Kopf and Matthias Lange, they told me what they wanted from me and expected for that project.

At first step I was quite lost, but when days passed on project became a drawing. Sometimes go forward one step and two back, but project never stopped. What you have in your hands is the result of a semester of work.

I liked to work in that project, I learnt and went further in the ambit of CPT, it is in fact interessant, and think how that device gives to the experts information that they will use to determinate if the soil and place is right for set and structure.

2. ARTICLES AND CONDITIONS

2.1. Rules and catalogue of the materials used

2.1.1. O-rings

2.1.1.1. For sealing

The rubber selected is NRB90, as it is possible appreciate in the catalogue 1.4.1. that material has good marks in a vast mediums, but also has the best mark in Sea water (Meerwasser). That material is used for that kind of device, CPTs.

2.1.1.2. Porous O-ring

2.1.2. Steel

The steel used for calculate the thickness of house's wall is 304 stainless with elastic limit of 210 N/mm^2.

The steel used for calculate the micro deformations by Solid Edge is also steel 304 stainless.

The steel that was going to use to calculate micro deformations in laboratory is 14435. That activity was not done because the intensifier that was ordered has not come on time, then projects end.

2.1.3. DMS

For chose the ideal DMS for our CPT it is required to know which micro deformations Test-stick has. For that there were three ways:

One in laboratory that was explained in previous point (2.1.2)

Second one is simulate by Solid Edge the forces on Test-stick and then know which ones are the micro deformations that it has. With that information go to stalemate and choose one DMS in this range.

Third and last one is calculating by analytically using formulas.

The last two are done in step 3.1.

It is espoused that the step in laboratory should be from here at a time by another responsible of that project.

2.2. Assembly procedure

Have a look at picture 4.1.1 and 4.1.2 at 4.1-General views.

2.2.1. Items required

2.2.1.1. Cone

Look at picture (4.1.7) in 4.1-General views.

That item is and standard part as it is said in the project's background. The features are 60° of inclination and the section-cross an area of 15 cm2 (in that project).

It has a hole through the item form the surface to the centre. It is through water from the Sea that will go in when the CPT goes down in the depth.

2.2.1.2. Test-stick

Look at picture (4.1.3) in 4.1-General views.

It has two functions: first one is blending itself by impact CPT against the Sea bottom and the second one is give a rout to the water for going up to the ship.

It is symmetrical; in each extreme are the same thread and groove for the O-ring.

It has a hole of 5.5 mm of diameter that through all of the item.

2.2.1.3. Anell

Look at picture (4.1.9) in 4.1-General views.

That item was devised for reduce the cost and save material and easier manufacturing.

Anell has the function with an O-ring in its groove to keep the water out of the CPT from the bottom of House.

It save material because the other alternative was to mechanize a stick with the diameter of Anell, then eliminate all the material of that stick to have the size of Test-stick, and leaving the thickness of Anell and diameter. It means to loss a vast of steel and of course it wastes money, material and time.

It is so easy have a stick with the same diameter of Test-stick, then make a hole crossing its inner, mechanize both extremes making threads and then get a section of same measures of Anell mechanize a groove, thread and the hole.

2.2.1.4. House

Look at picture (4.1.4) in 4.1-General views.

It is just a house to cover and protect the inside of CPT of water and pressure. It has a thread at the top extreme for joining it to the Joint.

2.2.1.5. Joint

Look at picture (4.15) in 4.1-General views.

That item is symmetric crossing a line in its middle that is because an easier mechanization and it does not matter which side goes up or down.

2.2.1.6. Tub

Look at picture (4.1.8) in 4.1-General views.

It is a steel tube with two threads, one at each extreme with one O-ring in them.

2.2.1.7. Closet

Look at picture (4.1.6) in 4.1-General views.

Its functions are as a house, keeping safe the inner of CPT; as joint to the ship, because of it has a thread that is linked to; and as a box, for holding the microprocessor.

2.2.1.8. Seals

Look at pictures (4.1.10 to 4.1.13) in 4.1-General views.

There are different sizes of the same material (NRB90) for each item, but also there is a porous O-ring.

2.2.1.9. DMS

They are so thin and small and should be manipulated carefully.

2.2.2. Steps for assembly

2.2.2.1. Setting Seals

That process should be the first when it is going to assembly the CPT. That is because a vast of O-rings goes between items, so then, after joining them it is impossible setting the seals.

Also that process actually is so important inasmuch as a seal settled by the wrong way, then working down to Sea and water comes in and ruins the CPT's electric parts.

The assembly seals should be cheeked to be sure that everyone is well assembled.

Below, it is explained each item and how the seals go in them. Items are referenced by pictures at the beginning of paragraph for getting a better idea how they are and seals set in them.

2.2.2.1.1. CONE

Look at picture (4.2.4) in 4.2.

The O-ring we use for Cone is porous O-ring, that is the only special one is in CPT.

2.2.2.1.2. TEST-STICK

Look at picture (4.2.1) in 4.2.

It has to wear two threads at the ends for joining it with the Cone in one side and the other with the Joint. Before those threads there are one seal in each extreme to keep sealing the water inside the pipe and not damage the inner of CPT.

2.2.2.1.3. JOINT

Look at picture (4.2.2) in 4.2.

. It has two seals peer that goes in two grooves both close to the middle of the item. So them should be assembled.

2.2.2.1.4. CLOSET

Look at picture (4.2.3) in 4.2.

It has only one seal, that is settled at the top of it.

2.2.2.1.5. ANELL

Look at picture (4.2.6) in 4.2.

In this case the seal was thought first, and then for to hold the seal was designed the Anell.

2.2.2.1.6. TUB

Look at picture (4.2.5) in 4.2.

Like Test-stick, Tub has two seal and are settled same places.

2.2.2.1.7. HOUSE

It is the only item in CPT that has not one seal.

2.2.2.2. *Joint Items*

For assembly CPT, we need first have settled the seals. Once it have done go procedure to built CPT. Although it could be thought that there is another way to assembly the CPT, the following method is for what that project was focused and design the items for that.

Set the DMS to the surface of Test-stick. Clean the surface and put the glue, then add the four DMSs. Let few minutes for the glue gets dry. The cable that goes from the microprocessor to the ship should be connected to microprocessor and the other extreme should be hanging out the joint.

Now get the Joint clean the bottom inner then put glue and add the microprocessor, then pass through it the wires, let them in the middle way for crossing, so link the Test-stick to the Joint, turning by the thread. Connect the wires to the DMSs.

Following link the Anell to the Test-stick, and then to Test-stick also, connect the Cone. Now get the House and turn it to the Joint. In that point we are almost finished.

Set the Tub to the Joint. Now get the Closet and pass through the wire to the hole that Closet has for it. At that time put the Tub to the middle hole that Closet has and turn them, carry on that and the Joint also will be linked.

Now, all the items are assembled, rest stop get the seal for the wire, pass the wire for its inner and set the seal to the Closet.

Here CPT has already assembled.

3. CALCULATIONS

3.1. Test-stick

(hardness and deformation against the bump to the Sea's bottom)

3.1.1. Analytically; Formulas

$\boxed{Al = (F * L_0) / (S * E)}$

Al: Deformation of stick

F: Force applied

L_o: Initial length

S: Stick's section = $\pi * r^2$

E: 210 kN/mm^2

- Defining each value for calculating Al:

F: 37 KN, corresponding at 25MPa

S: $\pi * r^2$, because our stick has a hole inside, we have 2 diameters, then the formula is: $\pi * (R^2 - r^2)$, so $S = \pi * (16^2 - 10^2) = 490\ mm^2$.

L_o: 215 mm

- Giving values and calculating:

$$Al = (37\ KN * 215mm) / (490mm^2 * 210(KN/mm^2))$$

- Result: AL=0,077 mm = 77Micras of deformation.
- The result we have had (77Micras) seems right for the conditions we summit the CPT. Now it would be nice have the result of deformation using the Solid Edge.

3.1.2. Computer; Solid Edge

When we open the program and then open the “item – Test-stick” we go to “simulation”, after that we choose whole test-stick, then choose the steel 304 stainless, assign the values of force, that is 37kN and choose the extreme where is linked to the “Cone”.

When we have already given all the features for the calculation, we just click on “calculate” and then we have some values, we should get the ones of micro deformations that is in different colors depending on the rate of micro deformation, we will get the average and it should be that average nearly 77Micras.

Inasmuch as it was calculate analytically in the step before and we got that value.

3.1.3. Empiric; Laboratory

In Laboratory, we get the Test-stick and get ready like weather it was going to be used to work into the Sea. That means that, clean the surface of Test-stick, put the glue on it, and then set the four DMSs, wait for they stick. Connect DMSs to the amplifier and that one to the computer.

Place Test-stick into the load machine, set it well and then start to gradually take the weight on Test-stick until 37kN.

Computer will show as graphic how the weight was producing a deformation on Test-stick.

The result would be a deformation around as analytically.

3.2. House’s thickness

When a body is going to bear pressure it is necessary calculate the thickness of wall. There is a vast of studies of calculating tanks and boilers. These bodies are just one piece, either because of they were made whole or they were made by welding pieces. Although that CPT is completely sealed, it is not one piece.

There are not any welds for joining the items that compose it. But we considerate as if weld was. That is because of there are not studies of how calculate the thickness of wall of a body made by different pieces and joined by thread as that CPT.

So, consideration CPT as a whole body it is necessary define how calculate, formulas, medium and properties of CPT.

The formula that is required is:

$$\boxed{t_v = (d_a * P_e) / (2*K*V_n / S)}$$

- As each symbol represents:

t_v: thickness of the wall

d_a: ID: internal diameter

P_e: supporting pressure

K: Steel elastic limit (N/mm^2)

S: safety factor from DIN2413-1

V_n: joint efficiency

- Defining each value for calculating t_v:

d_a: 44 mm

P_e: 100 bars = 10 N/mm^2

K: 210 N/mm^2

S: 1.6

V_n: 1

- Giving values and calculating:

$$t_v = (\,44mm * 10N/mm^2\,) \,/\, (\,2*210(N/mm^2)*1 \,/\, 1.6\,)$$

- The result is:

$$t_v = 1{,}68\ mm$$

This calculation is for 100 bars at 1000 meters of depth, the normally depth that that CPT is going to work, but for that project was required that it would be ready to work in more depth than 100 bars, thus now is going to calculate the maximum depth that is expected that CPT will work 300bars at 3000 meters.

- Defining again each value for calculating with new pressure t_v:

d_a: 44 mm

P_e: 300 bars = 30 N/mm^2

K: 210 N/mm^2

S: 1.6

V_n: 1

- Giving values and calculating:

$$t_v = (44mm * 30 N/mm^2) / (2*210^{(} N/mm^2)*1 / 1.6)$$

- The result is:

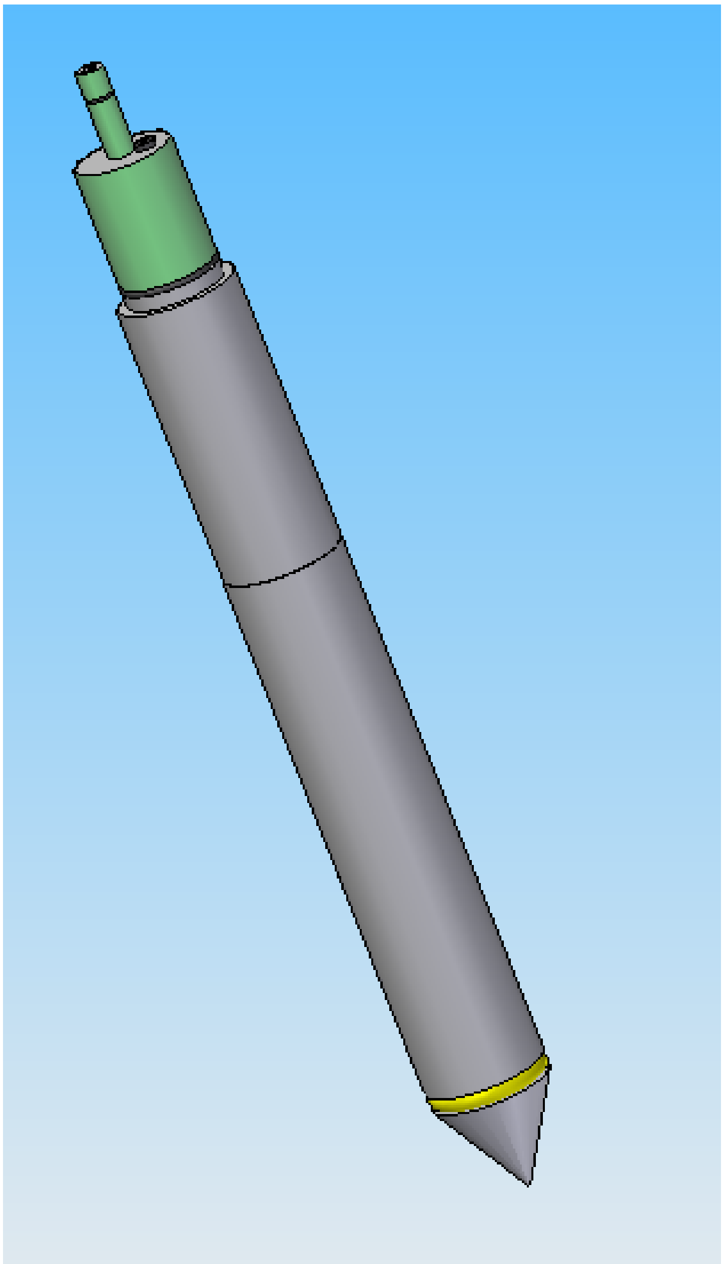
$$t_v = 5{,}03mm$$

With these results now we can design the house of CPT; House and Closet. So then, the external diameter of both will be 44 mm and the thickness wall 5 mm, that means that internal diameter will be 34 mm.

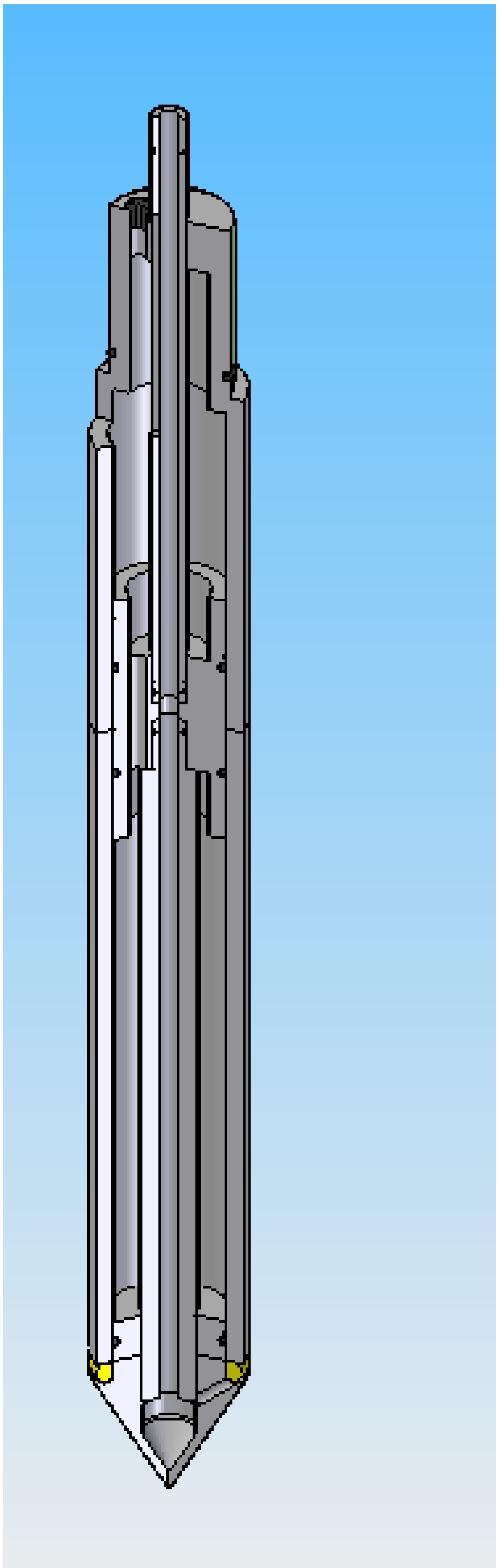
4. PARTS DRAWING

4.1. General view

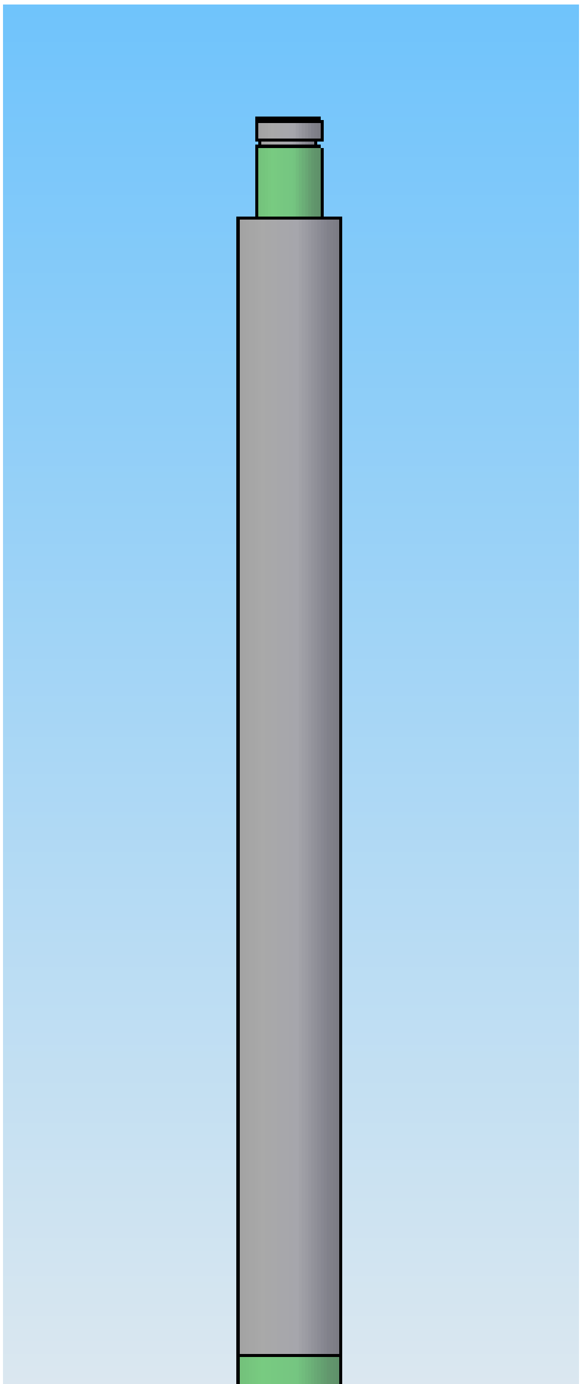
4.1.1. Whole CPT



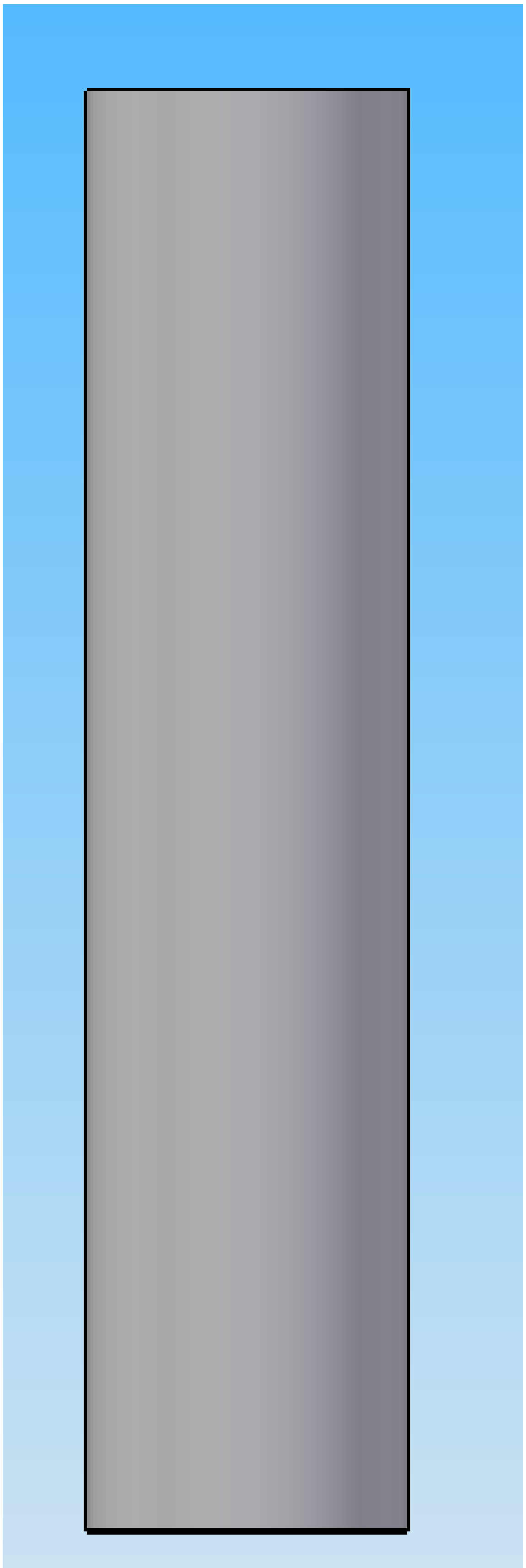
4.1.2. CPT sectioned



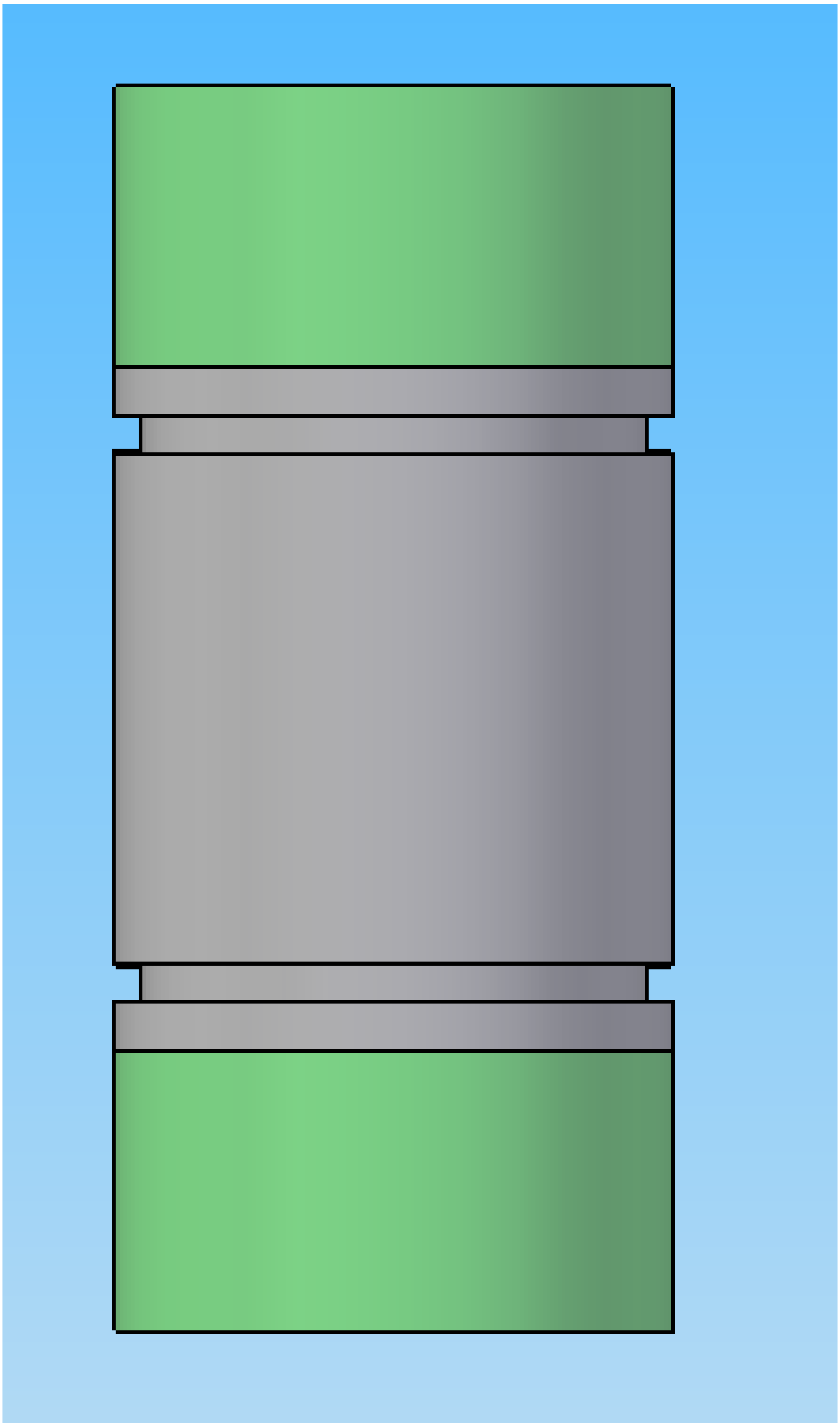
4.1.3. Test-Stick



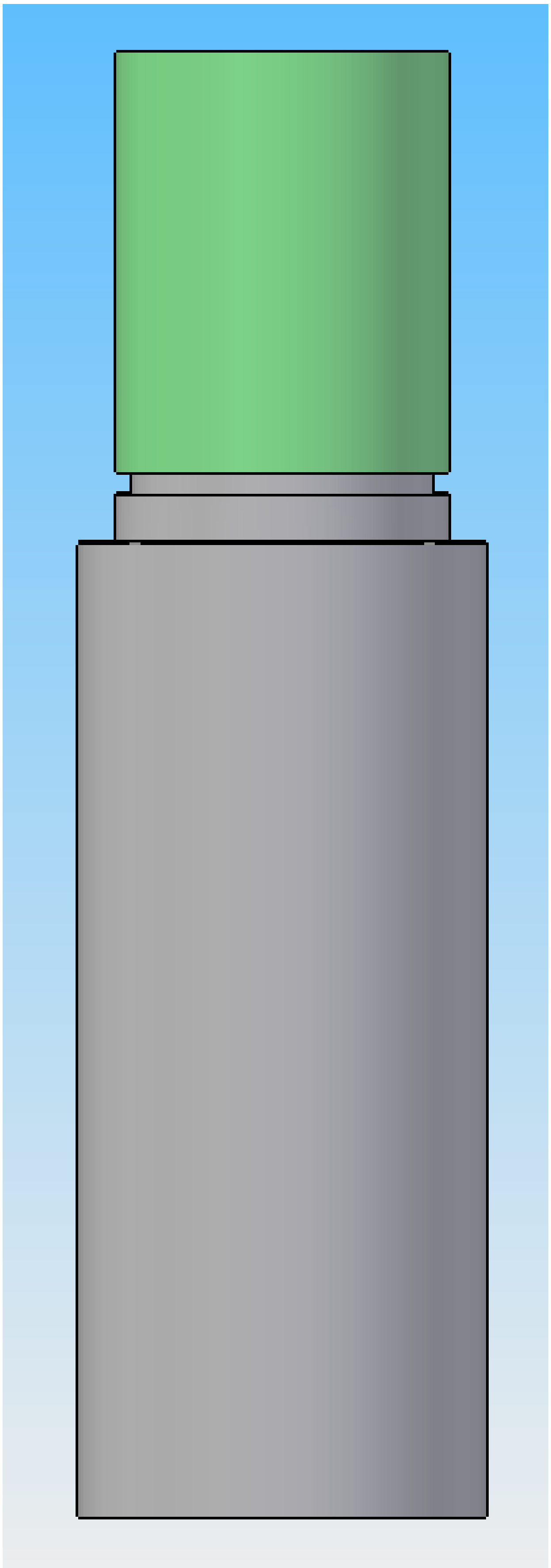
4.1.4. House



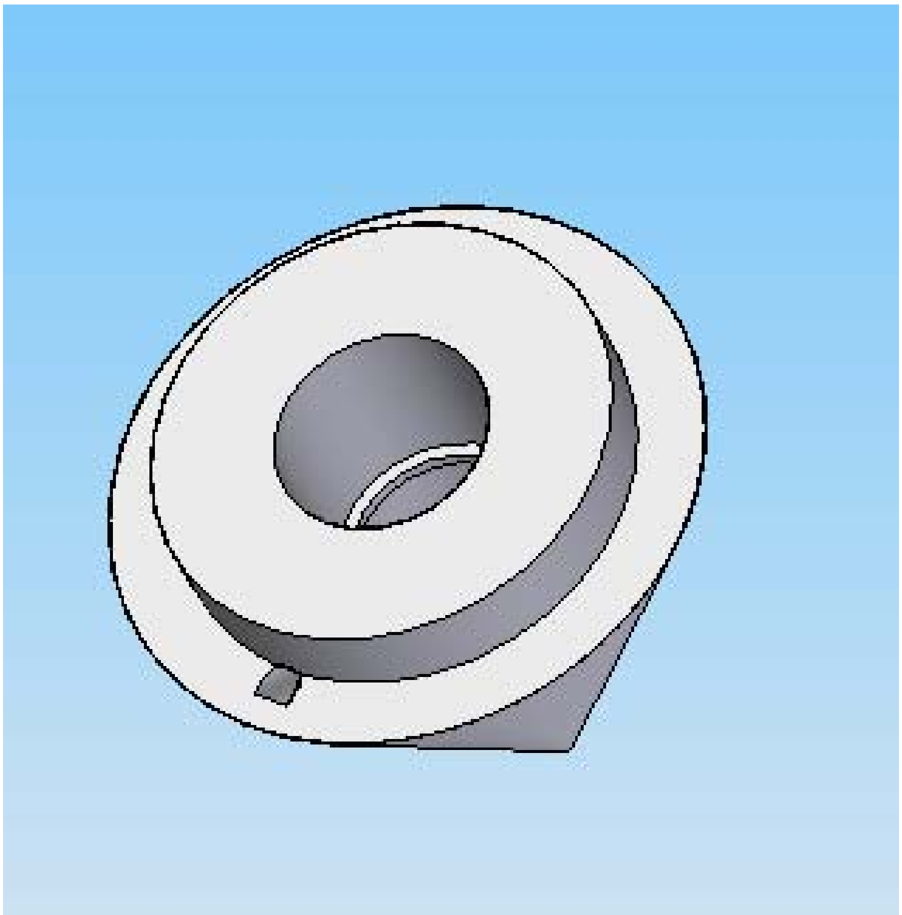
4.1.5. Joint

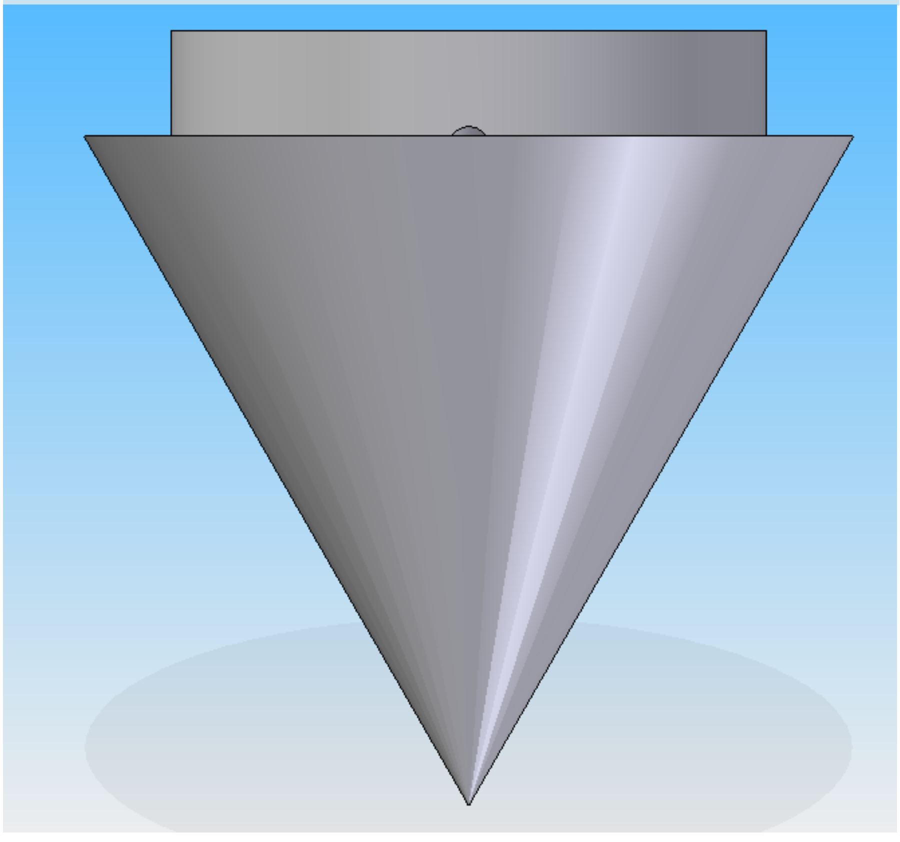


4.1.6. Closet

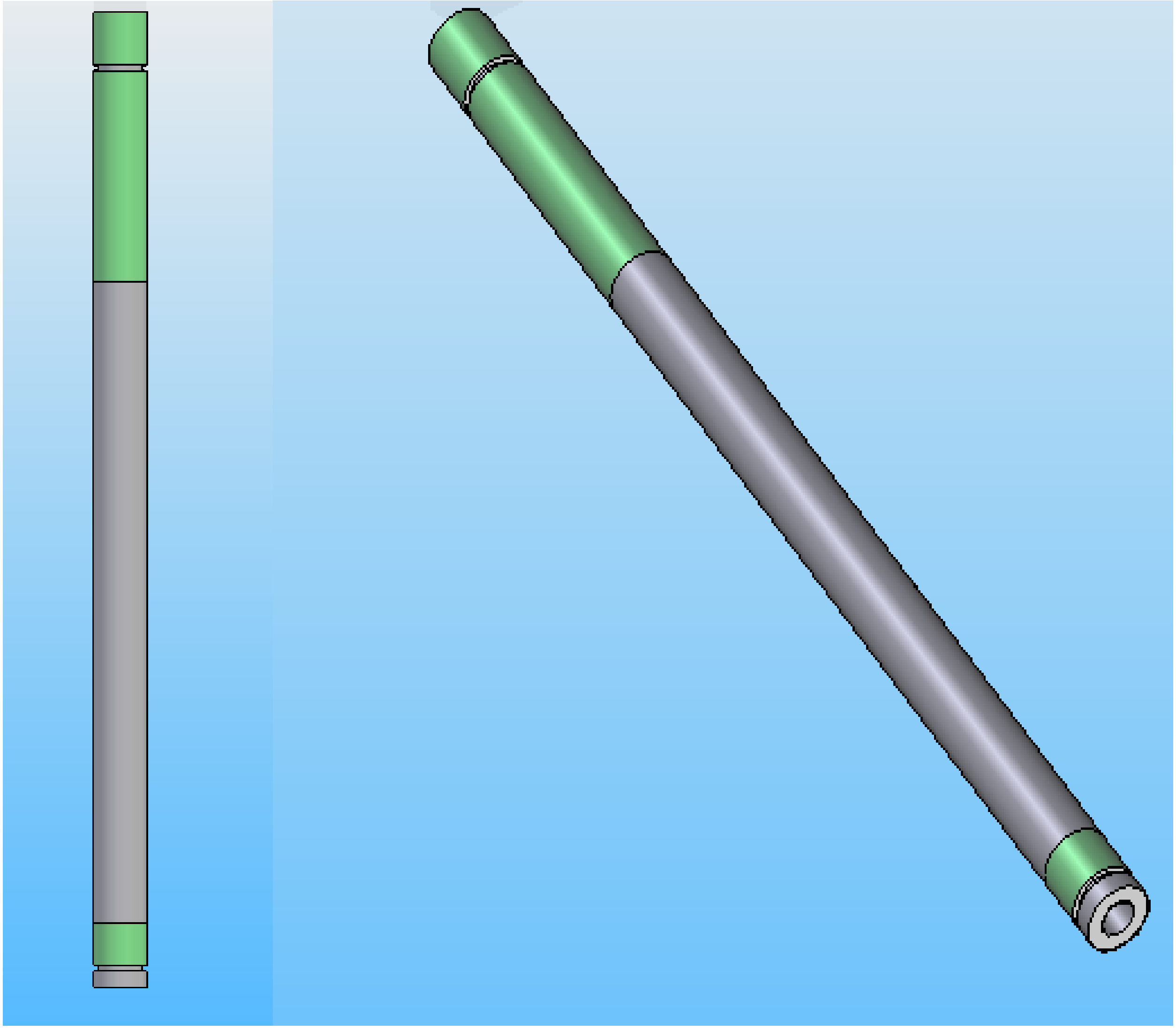


4.1.7. Cone

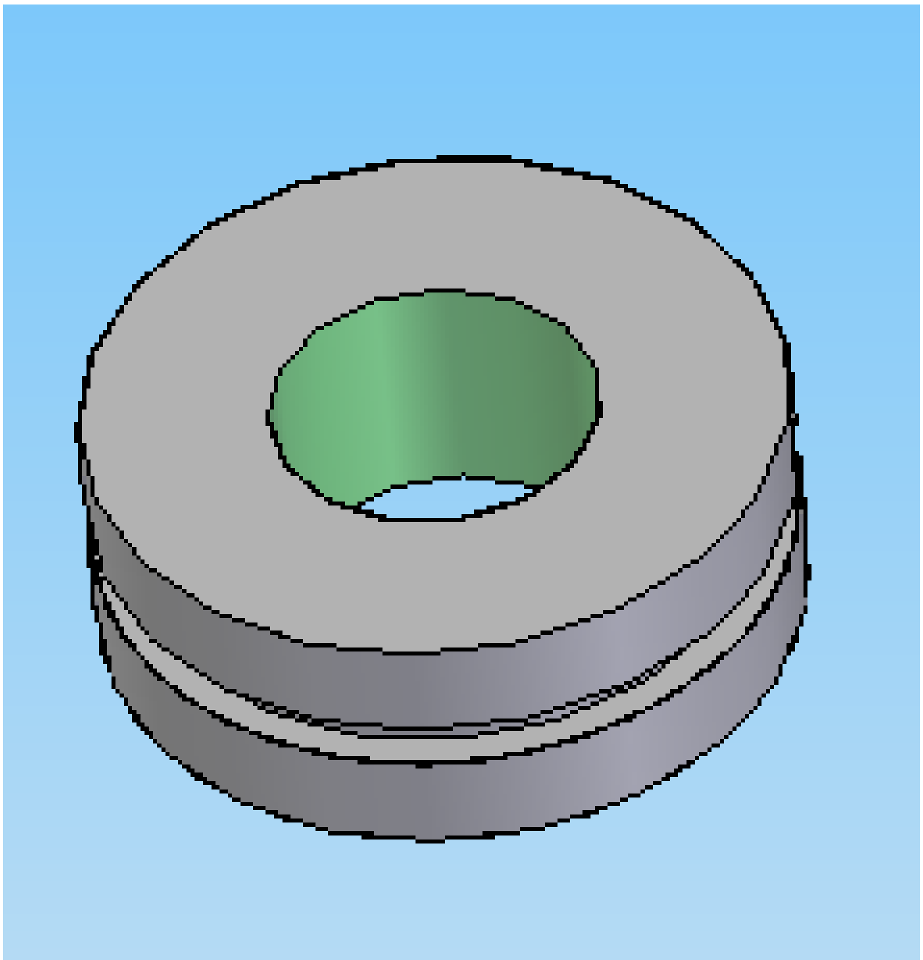




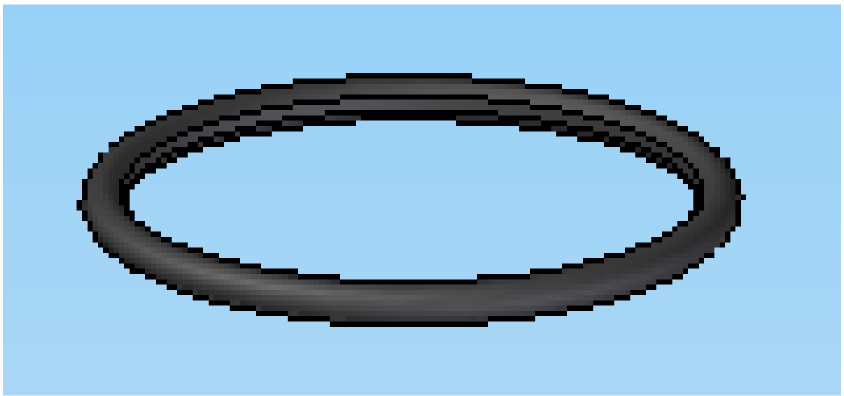
4.1.8. Tub



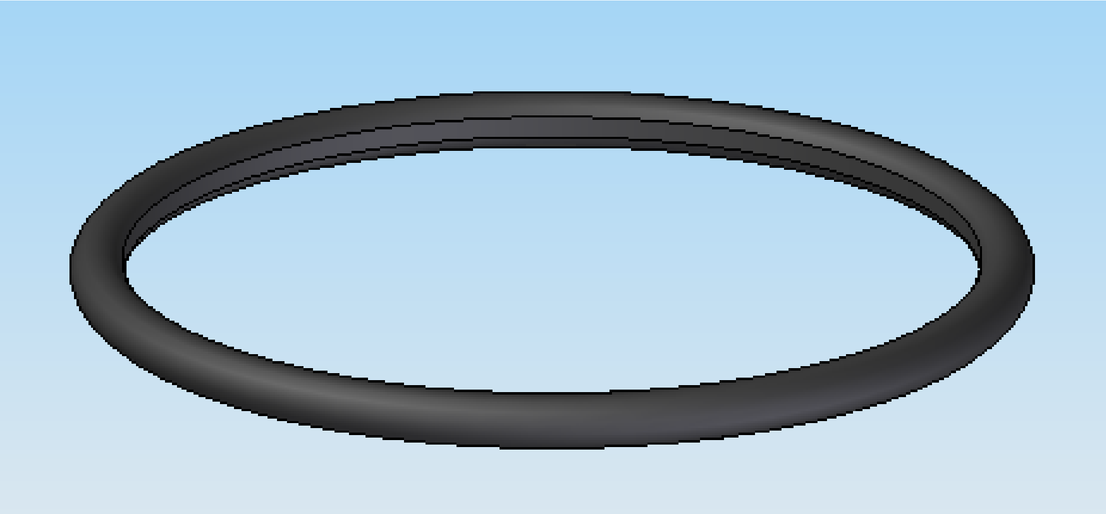
4.1.9. Anell



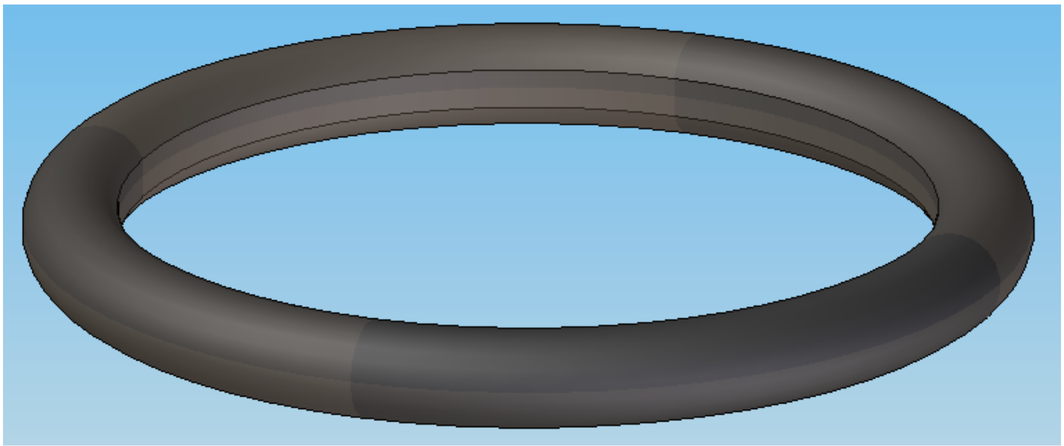
4.1.10. O-ring: Joint



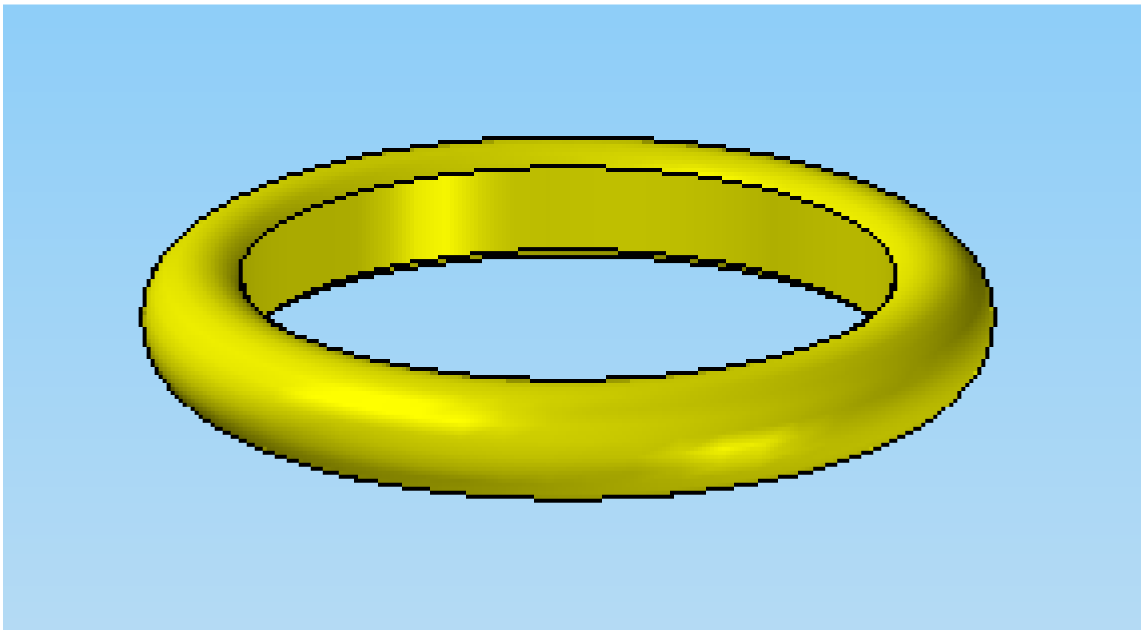
4.1.11. O-ring: Closet



4.1.12. O-ring: Test-stick

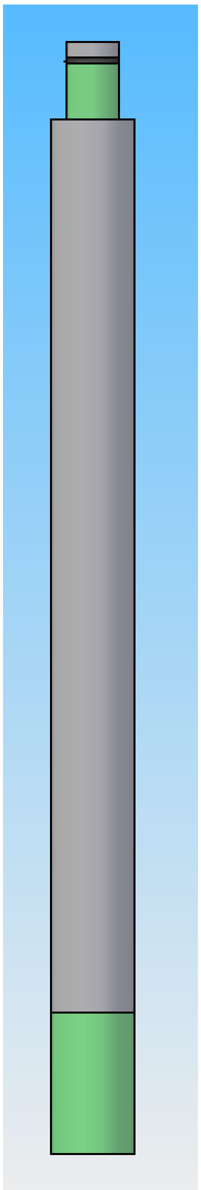


4.1.13. O-ring: Cone

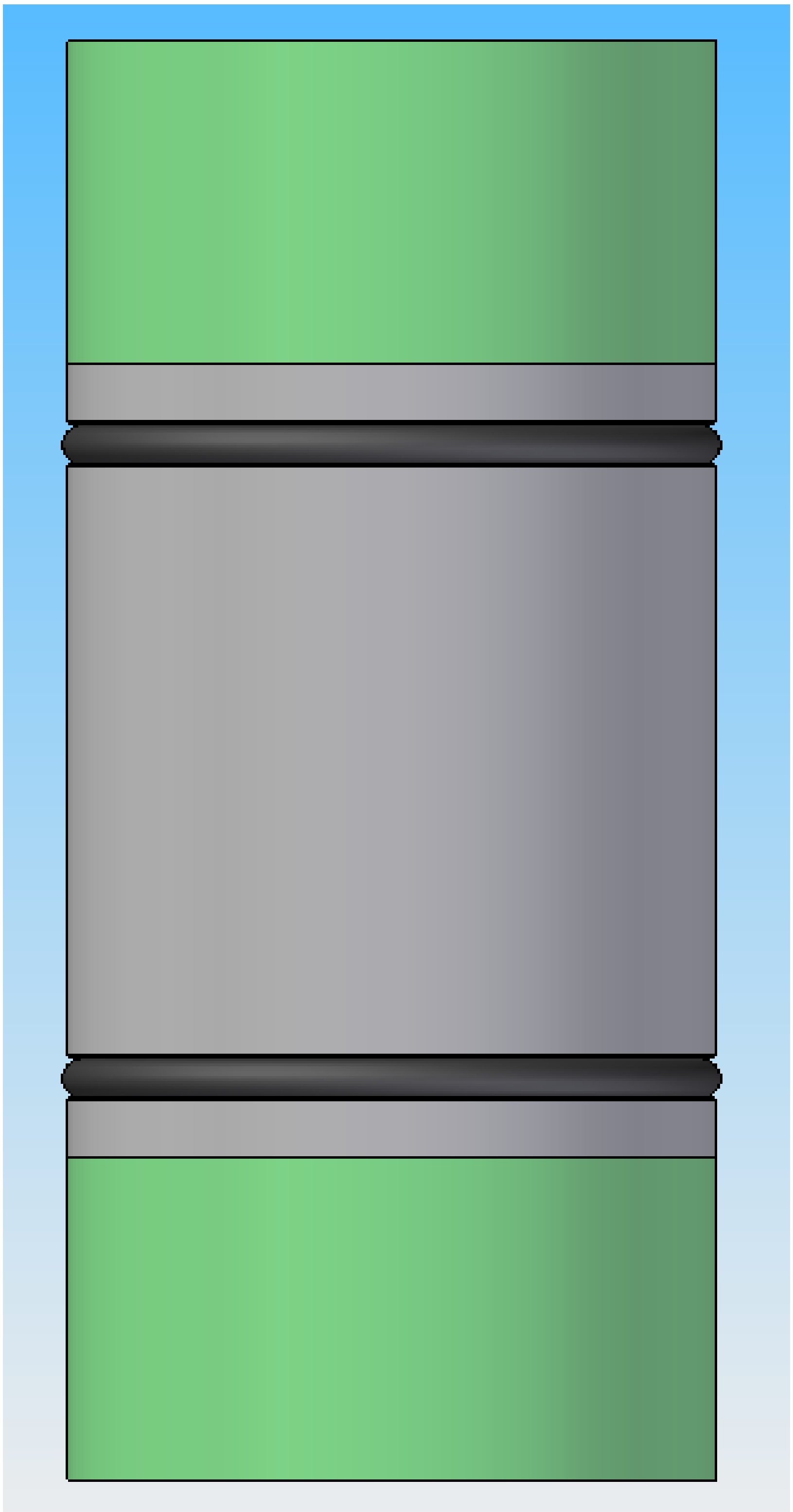


4.2. Item with seals

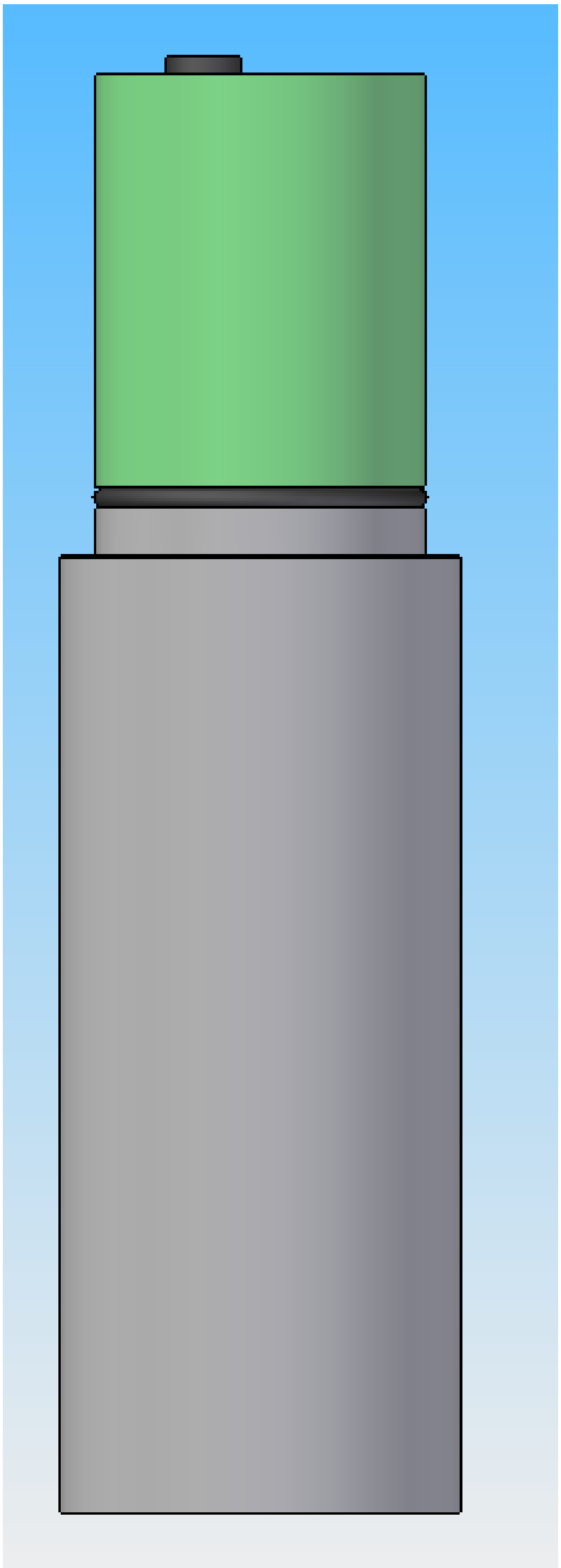
4.2.1. Test-Stick



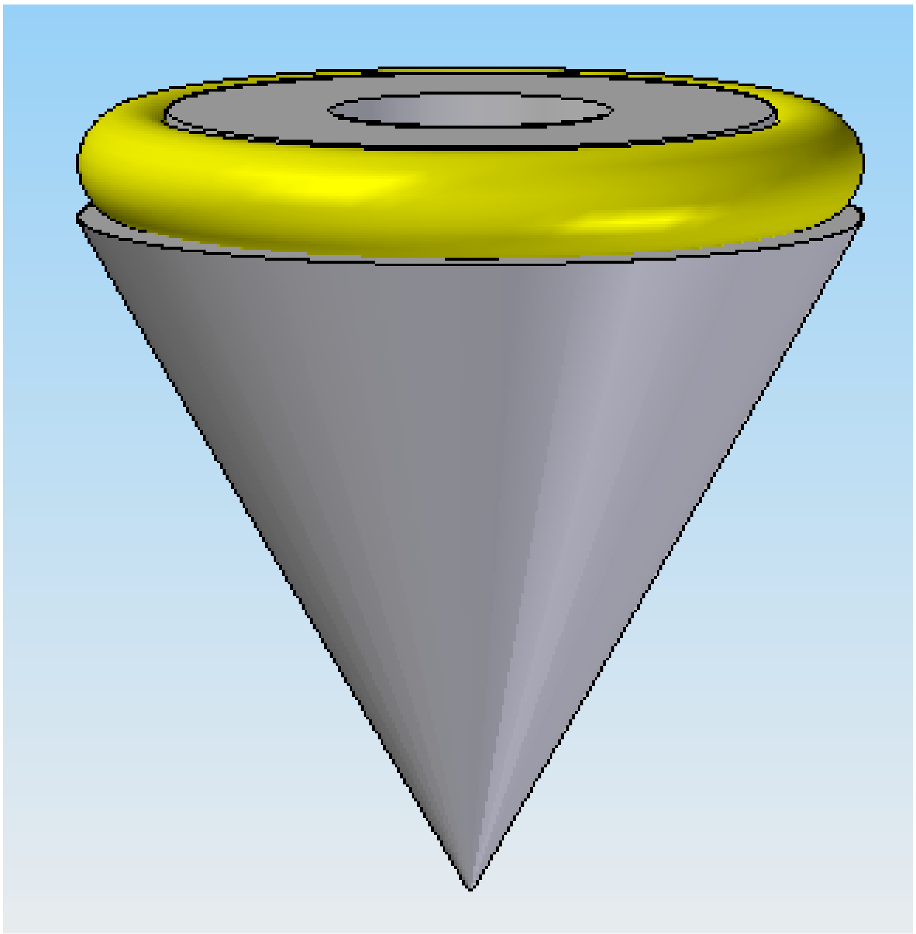
4.2.2. Joint



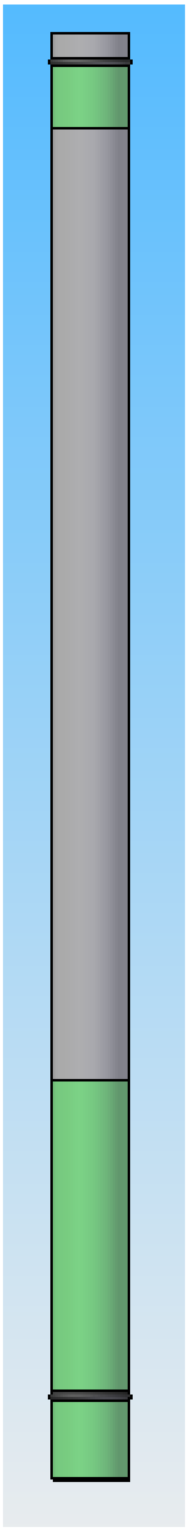
4.2.3. Closet



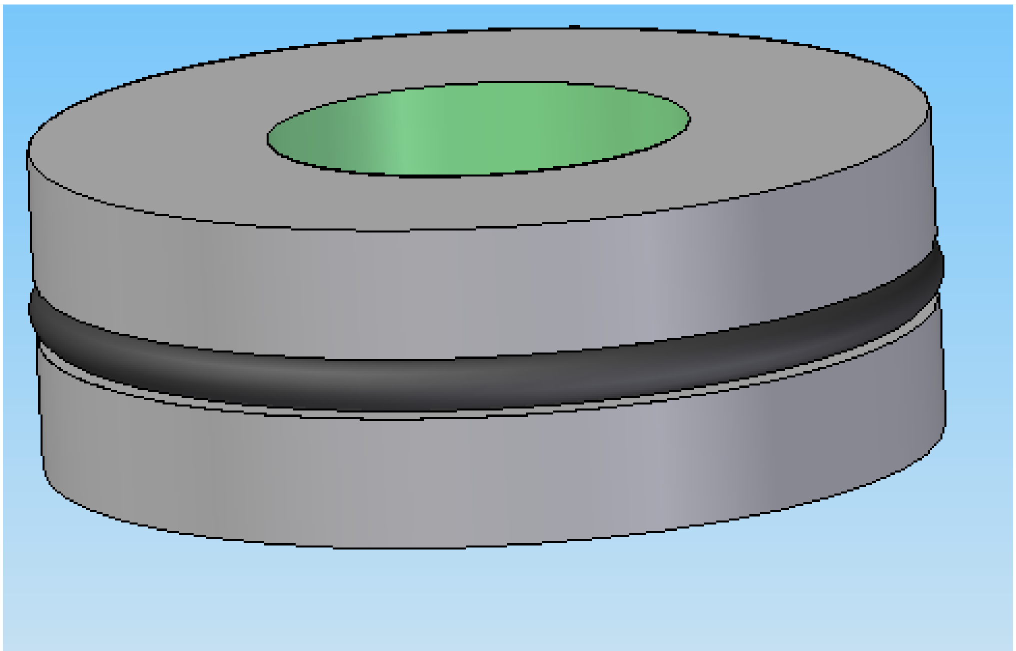
4.2.4. Cone



4.2.5. Tub



4.2.6. Anell



4.3. Sized pieces

(Each item in a drawing plane it is done in the add file)

4.3.1. Test-Stick

4.3.2. House

4.3.3. Joint

4.3.4. Closet

4.3.5. Cone

4.3.6. Tub

4.3.7. Anell

4.3.8. O-ring: Joint

4.3.9. O-ring: Closet

4.3.10. O-ring: Test-stick

4.3.11. O-ring: Cone

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- Dr. Matthias Lange, MARUM

5.2. Books

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  - by T. Lunne, P.K Robertson and J.J.M. Powell

- "In situ soil testing"
  - by J.J.M. Brouwer

5.3. Webs

http://en.wikipedia.org

http://www.conepenetration.com

http://www.kofler-dichtungen.at/technik/werkstoffe/nbr90shore.php

6. ANNEXA

6.1. Stalemate

(Stalemate are added in a file with this report)

- Stalemate - 1.4.1.B